TIME DOMAIN ELECTROMAGNETIC SURVEYS FOR ASSISTING IN DETERMINING THE GROUNDWATER RESOURCES ON WAIKOLOA LAND COMPANY PROPERTY NORTH WELL FIELD ISLAND OF HAWAII

Project Number 5068

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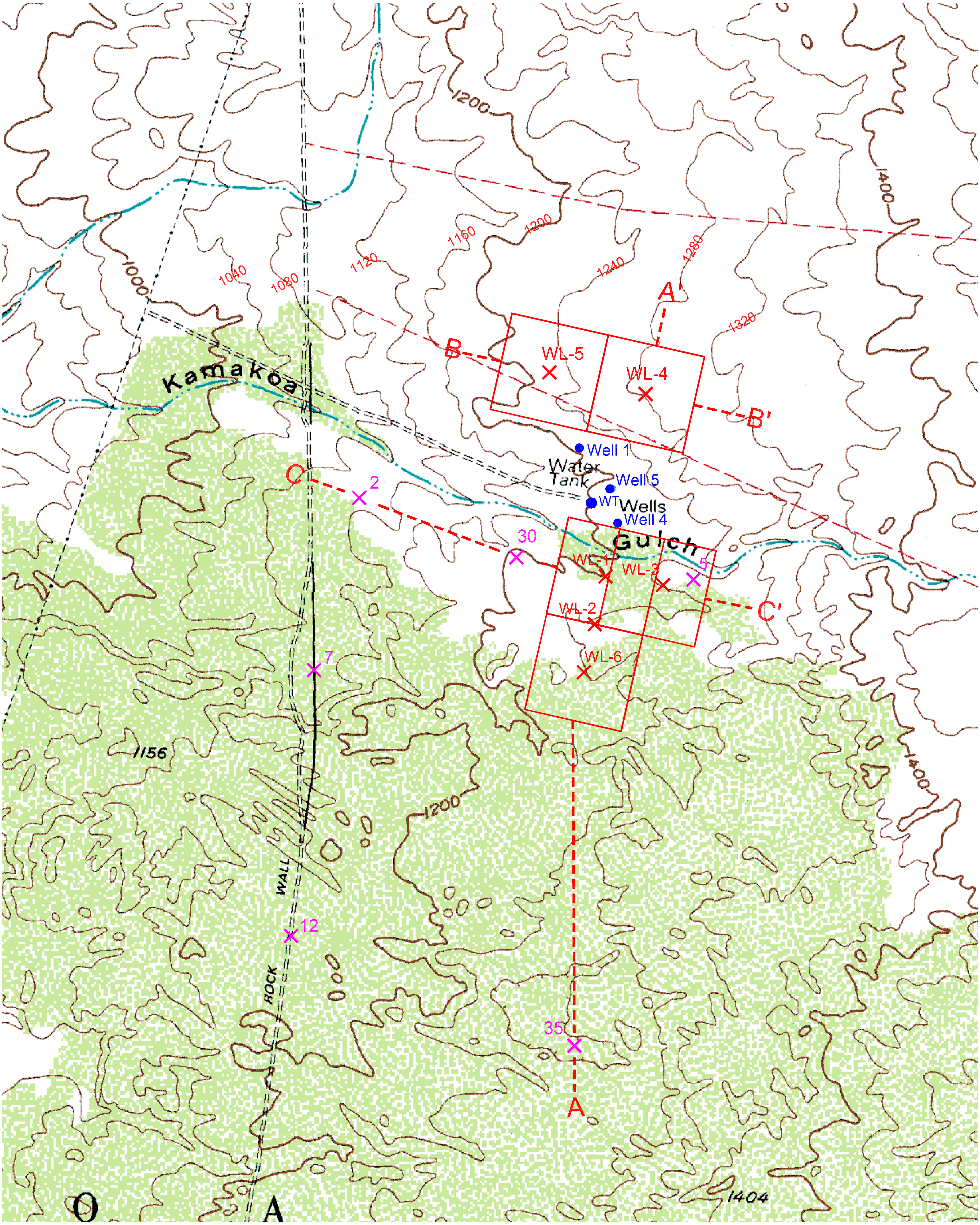
1.0 INTRODUCTION

This report contains the procedures and results of surface Time Domain Electromagnetic (TDEM) geophysical surveys performed for groundwater resource evaluation at the North Well Field on Waikoloa Land Company property located on the Island of Hawaii. ZAPATA ENGINEERING Blackhawk Division (Blackhawk) conducted the surveys from January 23 through January 26, 2007 for Tom Nance Water Resource Engineering (TNWRE) of Honolulu, Hawaii and Waikoloa Land Company (WLC) of Waikoloa, Hawaii.

The main objective of the TDEM surveys was to explore for additional basal groundwater occurrences at the North Well Field site. The surveys were conducted at six TDEM sites to help determine the optimum location for future groundwater wells located above Waikoloa Village. Figure 1-1 shows the combined locations of TDEM soundings taken during the 2007 survey and previous 1988 and 1990 surveys on the WLC property near the Kamakoa Gulch.

TDEM is a geophysical method that determines from the surface the geoelectric section (resistivity layering) of the subsurface. From the geoelectric section, information about geology and water quality can be inferred. This is possible because the electrical resistivity of the earth depends on lithology, porosity, the degree of saturation, and concentration of dissolved solids in the groundwater. Geophysical surveys, combined with other hydrogeologic information, are used to provide optimum locations for well placement and well completion depths.



Explanation

WL-5 TDEM Sounding 2007

7 Previous TDEM Data

A-A' Section Line

WT Water Tank

Well 5 Water Well

N

0 1000 2000

Scale in Feet

BLACKHAWK A DIVISION OF ZAPATA ENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company			Geophysical Survey Location Map *North Well Field* *Waikoloa Village, Hawaii*		
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5068	Date: Feb., 2007	Drawn By: HJV	Checked By: RJB	Scale: 1"=1000'	Figure: 1-1

2.0 GEOLOGY/HYDROGEOLOGY

Groundwater resources occur on the Hawaiian Islands basically in two modes:

- In a basal mode where a lens of fresh water floats on seawater, and
- In a high-level mode where the fresh groundwater occurrence is controlled by damming structures (i.e. intrusives, dikes, etc).

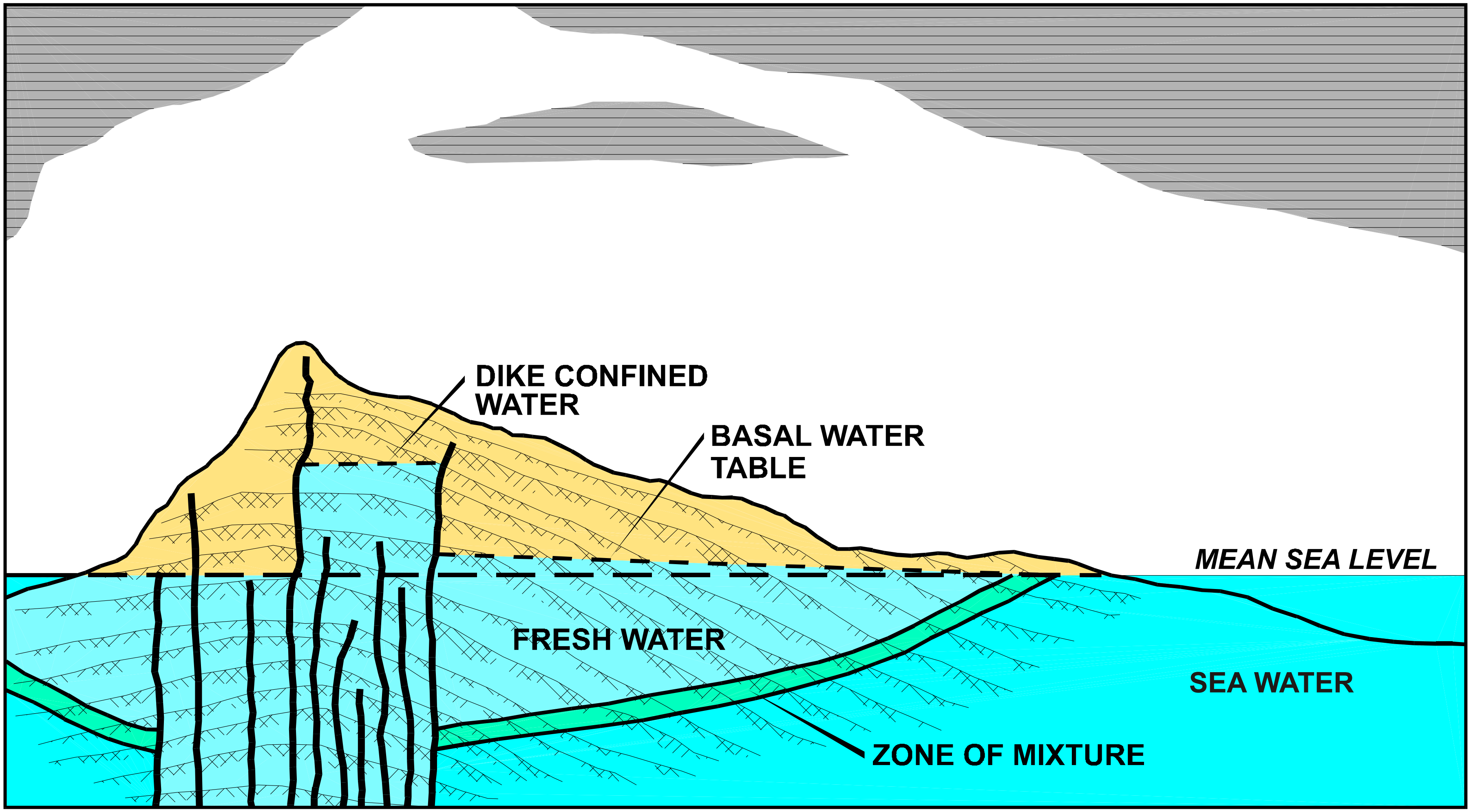
The basic geologic and hydrologic framework of the Island of Hawaii and the two modes of groundwater occurrences are illustrated in Figure 2-1. Fresh groundwater may also occur in areas between these two modes, but production is expected to be highly variable. TDEM surveys previously run on Hawaii have reliably mapped the basal mode groundwater occurrence and the boundary between fresh water in the basal mode and high-level water occurrences.

Basal mode groundwater is resting approximately at sea level near the ocean surrounding the Island of Hawaii. This is generally due to the fact that the volcanic rocks, which comprise the island, allow rainfall to percolate with little impedance directly downward through the rock mass (reference Figure 2-1). The fresh water floats directly on seawater encroaching from the ocean. Fresh water flows laterally toward the ocean causing the fresh water lens to be thinner near the ocean. When groundwater is under conditions of static equilibrium, the Ghyben-Herzberg Principle states that for every one foot of fresh water above sea level, approximately 40 feet of fresh water will exist below sea level as shown in Figure 2-2. The transition from fresh water to seawater at depth may be relatively sharp (i.e. occurring over several tens of feet) or more gradual, depending upon hydrologic flux, horizontal and vertical permeability contrast, and other geologic factors. It is assumed, when resolving TDEM sounding data, that seawater saturated volcanics begin at the midpoint of the transition zone.

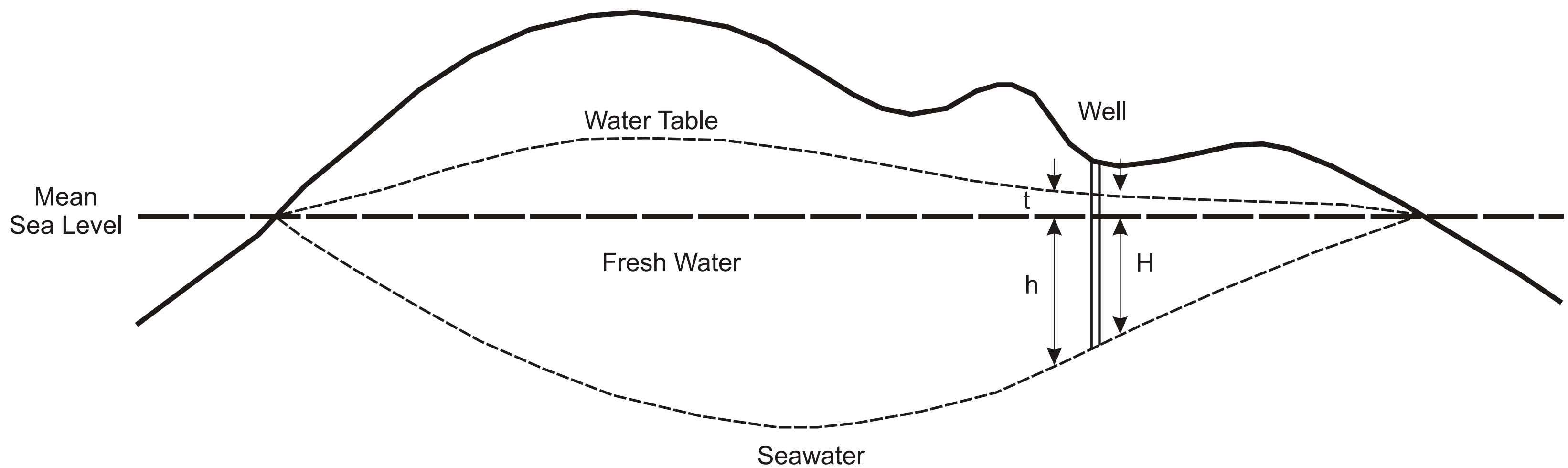
TDEM surveys are utilized to map the resistivity stratification of the subsurface. From numerous previous TDEM surveys and calibration at well sites, characteristic ranges of subsurface resistivities have been derived for the geologic/hydrologic units shown in Figure 2-3. Some overlap in resistivity occurs between the units; however, other factors (such as elevation) can be used to help separate the units. Therefore the main geologic/hydrologic units that can be derived from TDEM surveys are:

- Depth to seawater saturated volcanic rocks. This occurs in basal mode situations, and by using the Ghyben-Herzberg Principle, the thickness of the basal fresh water lens can be calculated.
- Weathered volcanic layers (laterite). These lower resistivity units are generally relatively thin (100 ft to 200 ft thick) layers that occur mainly at or near the ground surface.
- Clay poor and fresh water saturated volcanic rocks. These formations generally exhibit high resistivity values. Note that the extent of fresh water saturation is normally based on geographic and elevation information, and that fresh water cannot usually be directly detected in the TDEM data.

Groundwater damming structures (i.e. intrusives, dikes) are inferred with TDEM data by uncharacteristic sounding curves (distorted by 2-D structures), and by soundings that transition between detection of seawater at depth (indicating basal mode groundwater) and soundings that map high resistivities to depths below sea level (indicating high-level groundwater).



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company			Schematic Hydrogeologic Cross Section Island of Hawaii		
301 Commercial Road, Suite B Golden, Colorado 80401 — Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5068	Date: February, 2007	Drawn By: HJV	Checked By: RJB	Scale: No Scale	Figure: 2-1



$$t = 1/40\ (h)$$

From: Herzberg

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Tom Nance
Water Resource Engineering
Waikoloa Land Company

Illustration of the Ghyben-Herzberg Principle

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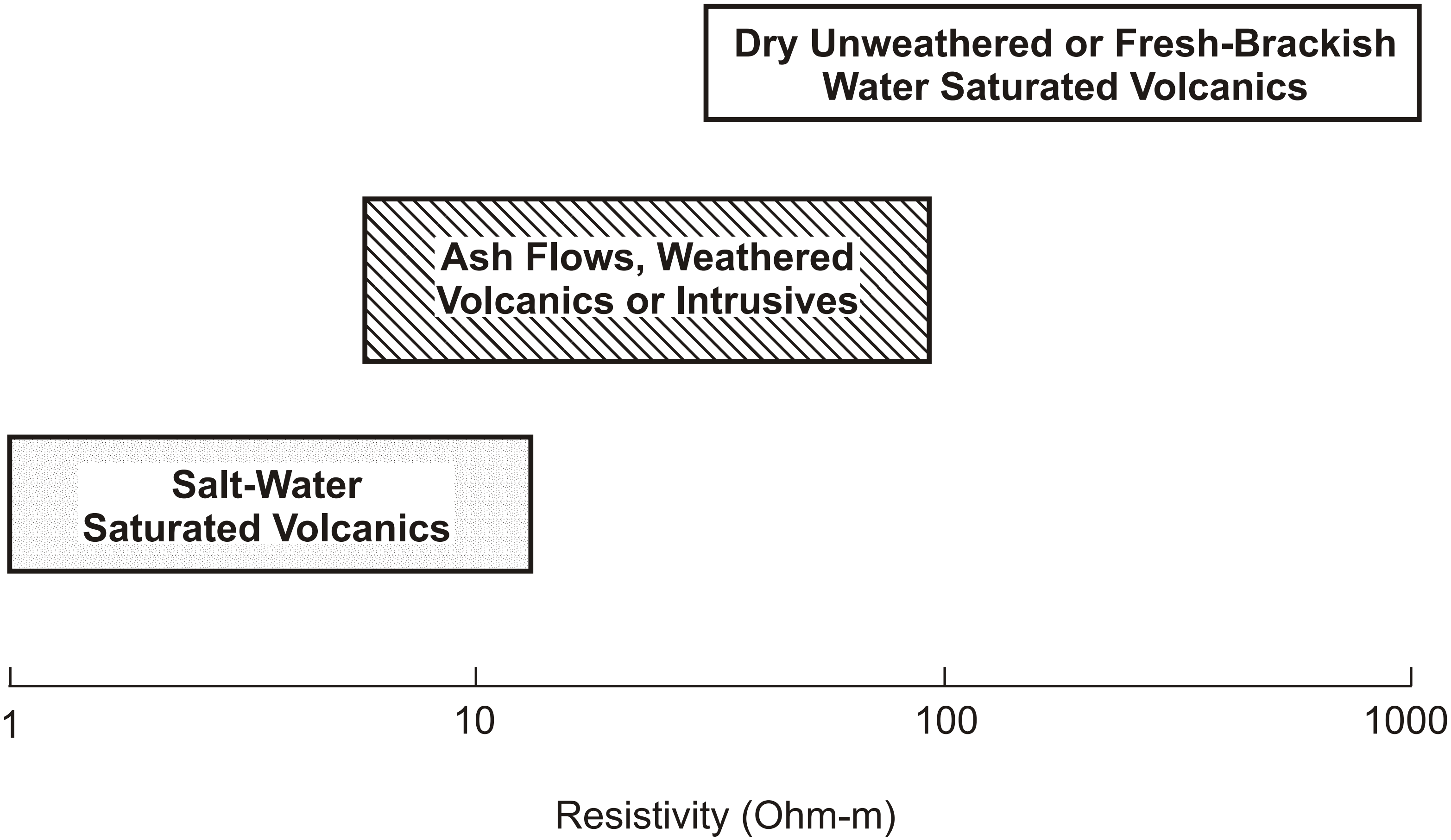
5068	February, 2007	HJV	RJB	No Scale	2-2



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company	**Characteristic Resistivity Ranges** *Island of Hawaii*

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5068	February, 2007	HJV	RJB	No Scale	2-3

3.0 DATA ACQUISITION AND LOGISTICS

Blackhawk mobilized a field crew consisting of a project geophysicist and geophysical technician to perform the geophysical surveys on the WLC property. The Blackhawk field personnel and TDEM equipment were mobilized from Golden, Colorado to Waikoloa, Hawaii. During the fieldwork, WLC provided one field helper for the project and site access to the North Well Field while TNWRE personnel provided project direction and oversight. A daily log of field activities during the TDEM surveys is presented in Table 3-1.

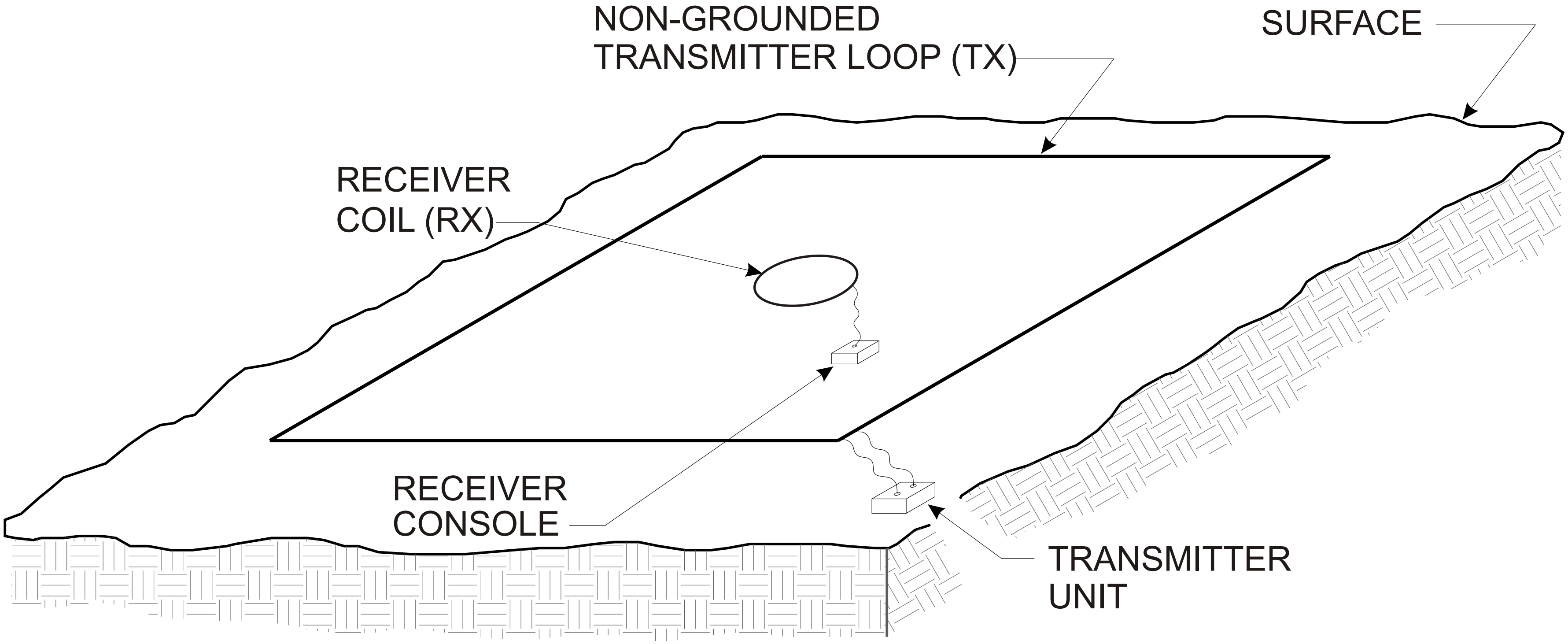
The geophysical equipment utilized for the TDEM surveys was the Geonics EM37 system. The EM37 system consists of both a portable motor-generator powered transmitter and a PROTEM digital receiver. The main purpose of the TDEM measurements is to derive both the vertical and lateral variations in the geoelectric section (resistivity) of the subsurface. To accomplish this, the TDEM measurements were acquired using a central-loop array at each sounding site. The square transmitter loops were constructed using 12-gauge insulated copper wire laid on the ground surface, as illustrated in Figure 3-1. The dimensions of the transmitter wire loops were 1,000 ft by 1,000 ft. The motor-generator and transmitter were placed at a corner of the wire-loop and square-wave current pulses were driven through the wire using a current of 15 amperes. The current pulses induce eddy current flow in the subsurface of the ground. A receiver coil (1-meter diameter) attached to the PROTEM receiver was positioned in the center of the wire-loop and used to record the decay of the secondary magnetic field due to the eddy currents induced in the subsurface. The effective exploration depth using a 1,000 ft by 1,000 ft transmitter wire-loop array has been determined to be approximately 2,500 ft. Greater exploration depths are reached with larger wire-loops and several factors that affect the depth of investigation include ground resistivity (ohm-m) and surrounding cultural interference (i.e. 60-cycle powerline, pipelines, etc).

The TDEM data acquired at each sounding consisted of measurements utilizing several receiver gain settings and two transmitter frequencies in order to ensure data quality and to obtain data over the longest possible time interval. The data were recorded at base frequencies of 3 Hz and 30 Hz for the TDEM soundings at the WLC property. For data quality control (QC) purposes, additional offset data sets were collected at designated locations (typically 100 ft) from the center of each sounding, for comparison to the central-loop data. The data from each sounding were stored in a solid-state memory logger in the PROTEM receiver and transferred at the end of each day to a PC for processing. The TDEM data collected with the PROTEM receiver were of excellent quality with only Sounding WL-1 being affected by cultural interference (i.e. pipeline, borehole casing, etc.) from a nearby underground pipeline from Well 4 to the 1200N Water Tank. A technical note describing the principles of TDEM with case histories is given in Appendix A.

The center and corners of each transmitter wire-loop were registered to the existing water wells located on the property. Other landmark features, such as water tank and fences, were also used to locate the corners of the wire-loops on the map with a compass and hip-chain. In addition, a hand-held global positioning system (GPS) was utilized to map both the receiver and transmitter locations of each sounding. The GPS information was used to position each loop center on the geo-referenced topographic map and the elevation was subsequently taken from that position. A total of six soundings were measured on the WLC property during the four days of fieldwork. The GPS coordinates and elevations of the TDEM soundings, water wells and water tank are given in Table 3-2 in Appendix B.

Table 3-1
Daily Log of Field Activities
WLC Property TDEM Survey

Date (2007)	Activity
January 16	Ship TDEM geophysical equipment from Golden, CO to Kona, HI.
January 22	Mobilize Blackhawk field personnel from Golden, CO to Kona, HI.
January 23	Unpack TDEM geophysical equipment at Kona Beach Hotel. Test motor-generator and organize equipment into 4WD vehicle. Meet with client, discuss WLC project and begin geophysical survey. Lay out and collect TDEM data on Soundings WL-1 and WL-2. Download data to PC and perform preliminary data analysis in hotel. Discuss results with TNWRE.
January 24	Recollect data on Sounding WL-2. Lay out wire and acquire data on Sounding WL-3 (Sounding 5, 1988). Pick up, lay out and collect data on Sounding WL-4. Download data to PC and perform preliminary data analysis in hotel. Discuss results with TNWRE.
January 25	Lay out and collect data on Sounding WL-5. Experience problems with crystal sync on PROTEM receiver. Perform field repair and repeat data on Soundings WL-5 and WL-4. Download data to PC and perform preliminary data analysis. Discuss results with TNWRE. Decision is made by TNWRE to collect data 500 ft south of Sounding WL-2.
January 26	Haul in TDEM equipment (generator, etc.) to NW corner of Sounding 6. Lay out and collect data on Sounding WL-6. Haul out wire and equipment. Download data and perform data analysis in hotel. Discuss results with TNWRE. Finish project.
January 27-February 9	Data on other projects in Hawaii.
February 12	Deliver TDEM equipment to FedEx at Kona Airport. Demobilize Blackhawk personnel from Kona, HI to Golden, CO.



BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company			Schematic layout of TDEM system with locations of TX and RX for Central Loop Array measurements		
301 Commercial Road, Suite B, Golden, Colorado 80401 — Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5068	Date: February, 2007	Drawn By: HJV	Checked By: RJB	Scale: No Scale	Figure: 3-1

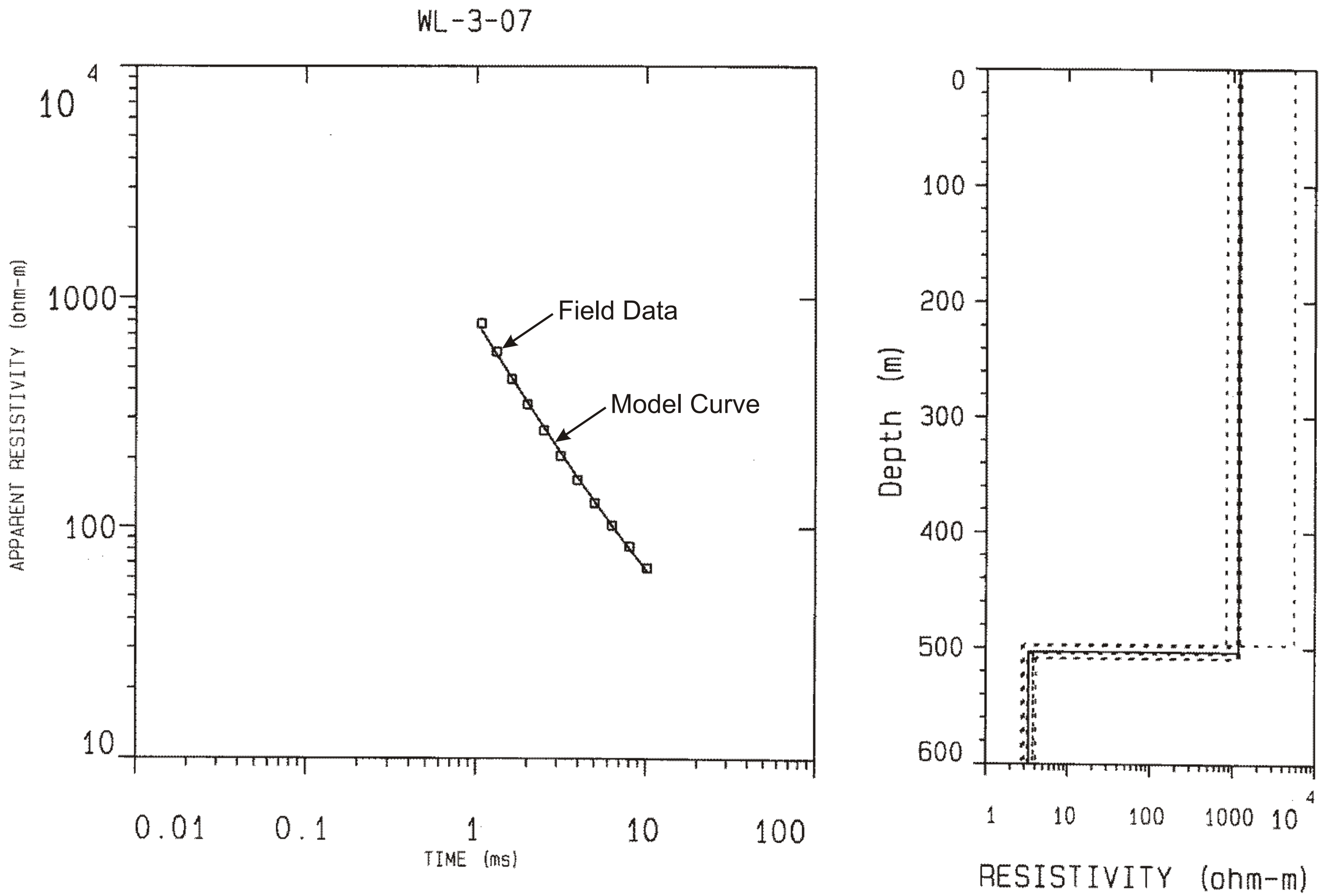
4.0 DATA PROCESSING

The field data collected for each TDEM sounding was transferred from the Geonics PROTEM digital receiver to a PC for editing and processing. Processing of the TDEM data starts with averaging of the electromotive forces recorded at positive and negative receiver polarities. Next, the measurements collected at the two base frequencies (3 and 30 Hz) and different amplifier gains are combined to give one voltage decay curve (transient). The electromotive forces in the various time gates of the decay curves were subsequently entered into the TEMIXXL (Interpex Ltd) inversion program to obtain a one-dimensional (1-D) geoelectric section that best matches the observed decay curve.

The TEMIXXL inversion program requires an initial model of the geoelectric section measured. The initial model includes the number of layers and the resistivities and thickness for each of the layers. This model is usually derived from general knowledge of the geologic section or from data obtained from drill holes or electric logs. The inversion program is then allowed to adjust the layer thickness and the resistivities, so that the model curve converges to best fit the field data. The inversion program does not change the total number of layers within the model curve, but allows all other parameters to change freely or they can optionally be fixed constant. To determine the influence of the number of layers on the solution, separate inversions with a different number of layers are run. Subsequently, the model with the least number of layers that best fits the field data is used.

An example of the output of the inversion program is shown on Figure 4-1 for Sounding WL-3-07. This figure shows the measured data points (in terms of apparent resistivity) superimposed on a solid line on the left panel. The solid line represents the computed forward model for the geoelectric section on the right panel. This geoelectric section is the best match obtained by the inversion program. Figure 4-2 shows the tabulated inversion parameters consisting of measured data, computed data for best match solutions and an example of the table of inversion statistics. A two-layer inversion model is shown for Sounding WL-3-07. The model displays a relatively thick (1,651 ft) resistive (1,180 ohm-m) upper layer overlying a second conductive (3.3 ohm-m) layer. The depth to the top of the second layer is located at -411 ft below sea level (BSL) in the section.

The interpreted geoelectric section derived from each TDEM sounding is not unique. The magnitude of each individual layer resistivity and thickness can normally be varied within a limited range with no significant change to the fit of the geoelectric model of the data. This variation is termed equivalence. An equivalence analysis was performed for each TDEM sounding. Figures 4-1 and 4-2 also show the equivalence analysis for Sounding WL-3-07. This sounding is typical of the TDEM data and shows a +/-5% equivalence in depth determinations and +/-10% in individual layer resistivities. The inversion results for each sounding of this project are given in Appendix B.



BLACKHAWK A DIVISION OF ZAPATA ENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company			Sounding WL-3 Example Inversion Output Apparent Resistivity Curve *North Well Field* *Waikoloa Village, Hawaii*		
301 Commercial Road, Suite B, Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	Project No: 5068	Date: February, 2007	Drawn By: HJV	Checked By: RJB	Scale: No Scale	Figure: 4-1

DATA SET: WL-3-07

CLIENT: TNWRE
LOCATION: Waikoloa, Hawaii
COUNTY: Hawaii
PROJECT: North Well Field, Well #4
LOOP SIZE: 305.000 m by 305.000 m
COIL LOC: 0.000 m (X), 0.000 m (Y)
SOUNDING COORDINATES: E: 3.0000 N: 1.0000

DATE: 01-24-07
SOUNDING: 3
ELEVATION: 377.90 m
EQUIPMENT: Geonics PROTEM
AZIMUTH:
TIME CONSTANT: NONE
SLOPE: 1.00

Central Loop Configuration
Geonics PROTEM System

FITTING ERROR: 4.544 PERCENT

L #	RESISTIVITY (ohm-m)	THICKNESS (meters)	ELEVATION (meters)	(H)	CONDUCTANCE (Siemens)
			377.8	1240.0	
1	1179.9	503.1	-125.2	-410.7	0.426
2	3.35				

ALL PARAMETERS ARE FREE

PARAMETER BOUNDS FROM EQUIVALENCE ANALYSIS

LAYER		MINIMUM	BEST	MAXIMUM
RHO	1	838.630	1179.960	5582.694
	2	2.766	3.352	4.115
THICK	1	496.790	503.186	509.232
DEPTH	1	496.790	503.186	509.232

Equivalence Analysis

CURRENT: 14.70 AMPS EM-58 COIL AREA: 100.00 sq m.
FREQUENCY: 3.00 Hz GAIN: 7 RAMP TIME: 160.00 muSEC

No.	TIME (ms)	emf (nV/m sqrd) DATA	SYNTHETIC	DIFFERENCE (percent)
1	1.06	26.86	29.55	-10.02
2	1.31	24.52	25.40	-3.58
3	1.61	22.06	21.69	1.69
4	2.00	19.00	18.40	3.19
5	2.50	16.11	15.38	4.57
6	3.14	13.38	12.73	4.83
7	3.95	10.83	10.41	3.84
8	4.99	8.60	8.41	2.19
9	6.31	6.71	6.70	0.115
10	7.99	5.08	5.26	-3.59
11	10.14	3.88	4.06	-4.66

PARAMETER RESOLUTION MATRIX:
"F" INDICATES FIXED PARAMETER

P 1	0.02		
P 2	-0.08	0.52	
T 1	0.01	-0.03	1.00
	P 1	P 2	T 1

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Waikoloa Land Company

Sounding WL-3
Example of Tabulated Data From Inversion
North Well Field
Waikoloa Village, Hawaii

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5068	February, 2007	HJV	RJB	No Scale	4-2

5.0 INTERPRETATION AND RESULTS

5.1 TDEM SOUNDING DATA

From each TDEM sounding, the geoelectric section of the subsurface is derived. The results of the one-dimensional (1-D) inversion of the individual TDEM soundings can be linked together (layers with similar resistivities) to create a 2-D geoelectric cross-section along a survey line. For this survey, a total of six (6) TDEM soundings were collected both north and south of Wells 1 and 4 at the North Well Field on the WLC property. The TDEM survey data indicates three geoelectric cross-sections which are presented on Figure 1-2. The correlations between geoelectric layers and lithologic units, presented on Figure 2-3, were used to interpret the geoelectric cross-sections.

5.2 GEOELECTRIC CROSS-SECTION – LINE 1 (A-A')

Figure 5-1 shows the layered geoelectric cross-section interpreted from the TDEM data acquired along Line 1 at the WLC property. These TDEM soundings were positioned both south and north of Well 4 and are situated in a south to north direction along the line. Sounding WL-1 was located 500 ft south of Well 4 and was determined to be distorted (probably by cultural interferences, i.e. pipeline, associated with the well infrastructure). Sounding WL-1 is shown on the cross section and labeled as distorted. The specific geoelectric section modeled for Sounding WL-1 was not used in the overall interpretation.

A two-layer cross-section is interpreted for the three soundings (WL-2, WL-4, WL-6) taken along Line 1. The upper layer in the geoelectric cross-section exhibits high resistivities that range from 921 to >1,000 ohm-m and is interpreted as dry clay and poor volcanic formations both above and below sea level. Where this upper layer occurs below sea level, it is expected to be saturated with fresh-brackish basal mode water. The second layer in the section with low resistivities (3.0 to 4.3 ohm-m) is interpreted as seawater saturated volcanic layers at depth beneath all the soundings. The calculated thickness of the fresh-brackish water lens ranges from about 310 ft beneath Sounding WL-2 to 493 ft beneath Sounding WL-4.

5.3 GEOELECTRIC CROSS-SECTION - LINE 2 (B-B')

The geoelectric cross-section from the TDEM data acquired from 2 soundings (WL-4 and WL-5) along Line 2 is presented in Figure 5-2. The two soundings were both located north of Well 1 in a west to east trend with the center of Sounding WL-5 at an elevation of 1,220 ft and Sounding WL-4 at elevation 1,280 ft.

A two-layer geoelectric cross-section is interpreted for the two soundings along Line 2. The upper layer in the cross-section shows high resistivities that are >1000 ohm-m and is interpreted as dry clay poor volcanic formations both above and below sea level. Where the layer occurs below sea level it is expected to be saturated with fresh-brackish basal mode water. The second layer in the section exhibits low resistivities (5.1 to 8.4 ohm-m) and is interpreted to represent seawater saturated volcanic layers at depth beneath both soundings. The thickness of the fresh-brackish water lens is calculated to be about 215 ft below Sounding WL-5 and 493 ft below Sounding WL-4.

5.4 GEOELECTRIC CROSS-SECTION LINE 3 (C-C')

This cross section includes data from Soundings 2, 5, and 30 taken in 1988, along with Soundings WL-1 and WL-3 taken during the present survey. WL-1 has previously been identified as a distorted sounding, likely caused by cultural features. Soundings 2 and 30, completed in 1988, interpreted the top of seawater saturated volcanics at elevations of -630 feet and -740 feet respectively. In both soundings, a three layer section was interpreted. A thick middle layer with resistivities from 9.7 to 14 ohm-m occurs in the soundings. This geoelectric section is anomalous when compared with other soundings in the area which all have an interpreted section consisting of two layers, a resistive upper layer (100's to 1,000's of ohm-meters) overlying a low resistivity layer (less than 5 ohm-meters). The resistivity range of the middle layer normally indicates a geologic section consisting of clay rich material or porous volcanics saturated with brackish groundwater. The data from the wells (drilling logs and water production) in the area along with the normal geologic conditions that occur in the Hawaiian Islands make these two alternatives unlikely. The TDEM soundings are interpreted assuming that the changes in the subsurface geoelectric/geologic section occur only in the vertical direction (only horizontal layering occurs in the immediate area of the sounding). If significant lateral changes occur, the sounding may be distorted and the interpretation flawed. It is possible that the 1988 Soundings 2 and 30 are distorted due to lateral changes in the geologic and geoelectric section. An alternative source of the distortion could be long linear metal pipes located within or immediately adjacent to the transmitter loops. The water lines which exist adjacent to the soundings are reported to be transite which is not electrically conductive and should not affect the soundings. The source of the potential sounding distortion is likely restricted in extent since it is not present in the data of other soundings within the area. It may consist of a steeply dipping layer of lower resistivity that acts as a barrier to groundwater flow.

Another anomalous feature shown in this cross section is the significant difference between the interpretation of 1988 Sounding 5 and the present Sounding WL-3. There is a 226 foot difference (-470 for WL-3 versus -670 feet for Sounding 5) between the interpreted top of seawater for soundings whose centers are only 300 feet apart. It has been approximately 18 years between when the two soundings were made and there has been significant groundwater production from wells in the area. The change in the water quality or the head in the production wells do not support the drastic change in hydrologic conditions. The cause for the difference in the soundings is not fully understood but may be related to the possible non-layered earth conditions that may exist in the area.

5.5 HYDROGEOLOGIC INTERPRETATIONS

Table 5-1 contains the thickness of the fresh-brackish water lens calculated from the elevation of the seawater interface interpreted from the TDEM data taken during the 2007 survey and from

1988 at the WLC Property. The table also includes the value of static water level (head) calculated by using the Ghyben-Herzberg Principle.

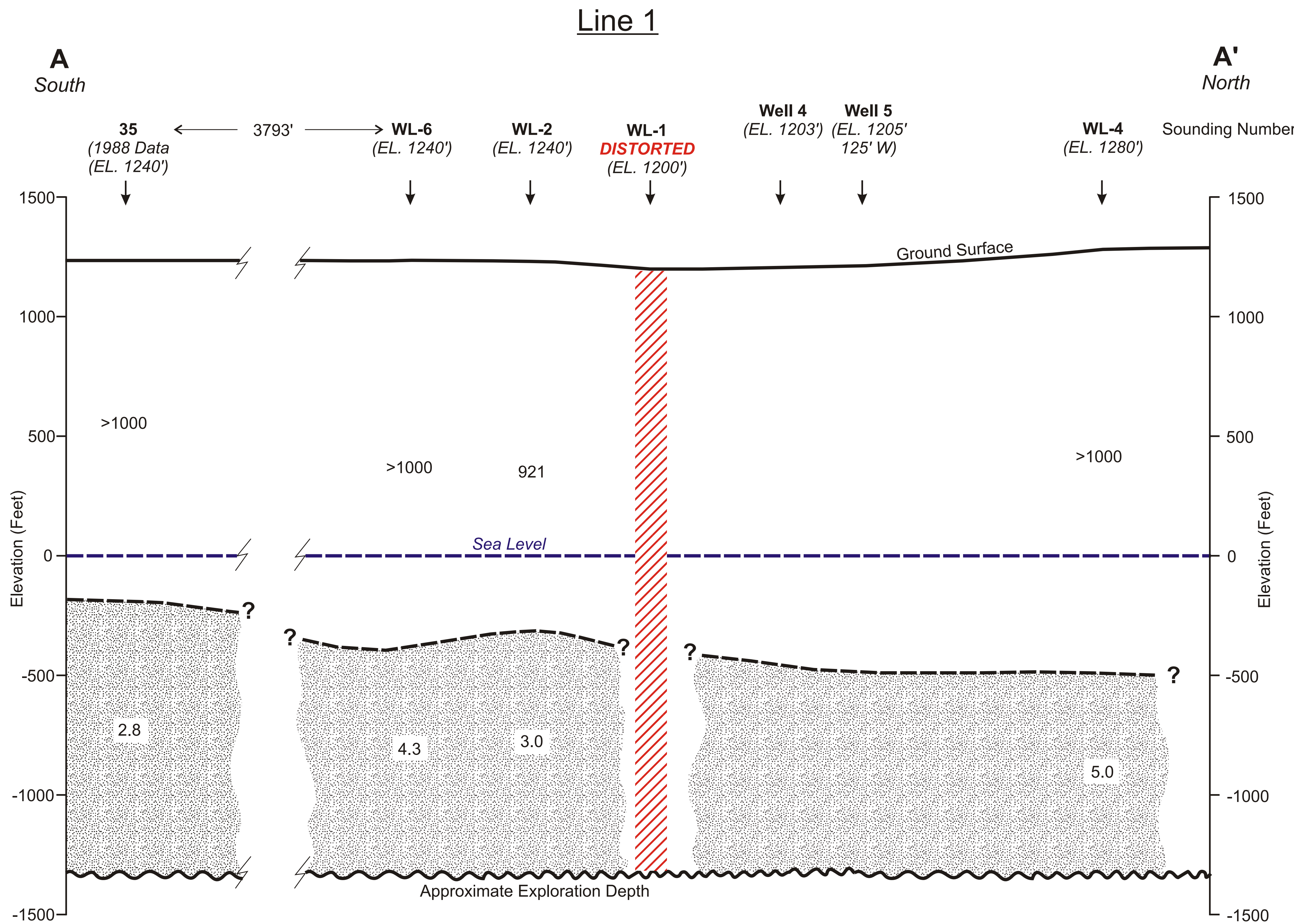
Table 5-1
Hydrogeologic Information Derived From TDEM Soundings
Waikoloa Land Company Property
(Values in Feet)

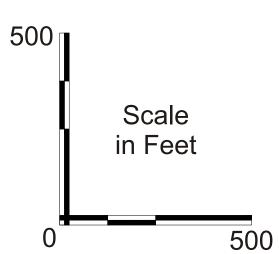
Sounding Number (Year)	Surface Elevation	Elevation of Top of the Conductive Layer	Calculated Static Water Level (Head) Using Ghyben-Herzberg Principle	Approximate Thickness of Fresh-Brackish Water Lens
WL-1 (2007)	1210	*	*	*
WL-2 (2007)	1240	-310	7.7	318
WL-3 (2007)	1240	-411	10.3	421
WL-4 (2007)	1280	-493	12.3	505
WL-5 (2007)	1220	-215	5.4	220
WL-6 (2007)	1240	-388	9.7	398
2 (1988)	1110	-630 (suspect)	15.8 (suspect)	645 (suspect)
30 (1988)	1220	-740 (suspect)	18.5 (suspect)	758 (suspect)
5 (1988)	1245	-696	17.4	713

*Because Sounding WL-1 was determined to be distorted by cultural interferences (i.e. pipeline) there is no calculation for this data.

The TDEM data from the survey is further summarized on the interpretation map shown in Figure 5-4. On this map the soundings taken during this recent survey along with several of the 1988 survey soundings were used to produce a contour map of the depth to the interpreted salt water interface. Due to the relatively large change measured from the repeated TDEM soundings (2007 Sounding WL-3 with 10.3 ft head and 1988 Sounding 5 with 17.4 ft head), the 1988 data is used here only for reference and not included in the final interpretation map Figure 5-4. As discussed above, the causes for the large differences in the calculated heads between TDEM Soundings WL-3 and 5 (1988) data taken near the Well 4 and the well itself (15 ft head, per com Tom Nance) are not fully known, but may be related to steeply dipping features which are distorting the TDEM data.

Although there is a measurable difference in the two data sets (2007 and 1988), it should be noted that the general trend of the saltwater interface contours are similar to the 1988 data. In both surveys the mapped thickness of the fresh/brackish lens substantially thickens from west to east over a relatively short distance. The rate of thickening of the lens indicated in the soundings suggests that a simple fresh water lens situation does not occur in this area and it is likely that there is some lateral impedance to groundwater flow. Based on the present TDEM data and the 1988 data it appears that the thickness of the freshwater lens decreases rapidly south of Kamakoa Gulch (Soundings WL2, WL6, and Sounding 35 (1988)). In addition, the TDEM Soundings 2 and 30 (1988) suggest a possible high angle "structure" south of existing well production. These two factors indicate that the areas east and north of the present well field (Wells 4, 5 and WW1) may be the best potential for groundwater production (reference Figure 5-4).





Explanation

3.0 Resistivity (oHm-m)

Resistivity Boundary (Dashed Where Uncertain)

Possible Distortion

Dry Clay Poor or Fresh-Brackish Water Saturated Volcanics

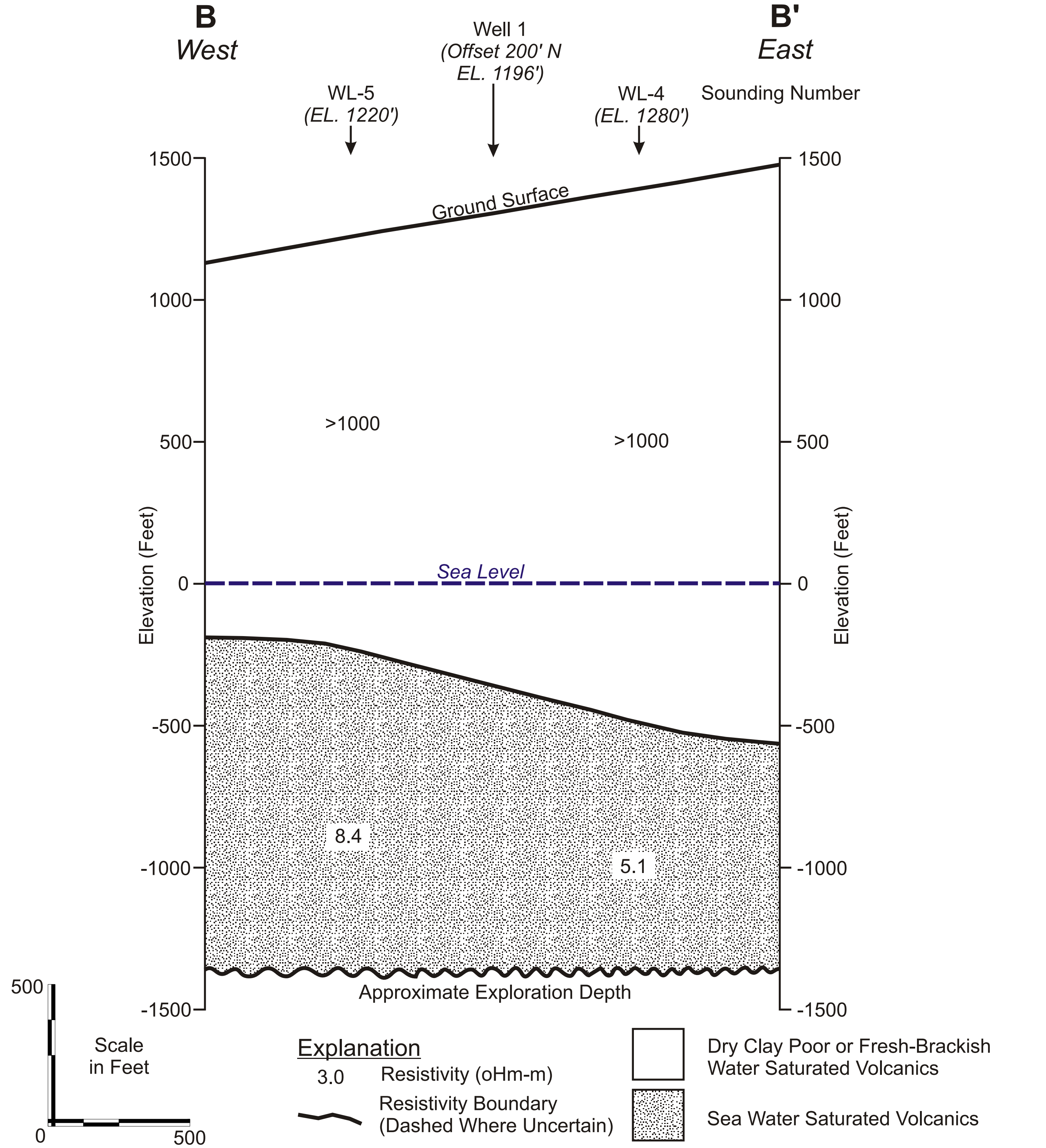
Sea Water Saturated Volcanics

BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company	Geoelectric Cross-Section from 1-D TDEM Inversions Line 1 - Transect A-A' *North Well Field* *Waikoloa Village, Hawaii*

301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5068	February, 2007	HJV	RJB	1"=500"	5-1

Line 2



BLACKHAWK
A DIVISION OF ZAPATA ENGINEERING

Tom Nance
Water Resource Engineering
Waikoloa Land Company

Geoelectric Cross-Section
from 1-D TDEM Inversions
Line 2 -Transect B-B'
North Well Field
Waikoloa Village, Hawaii

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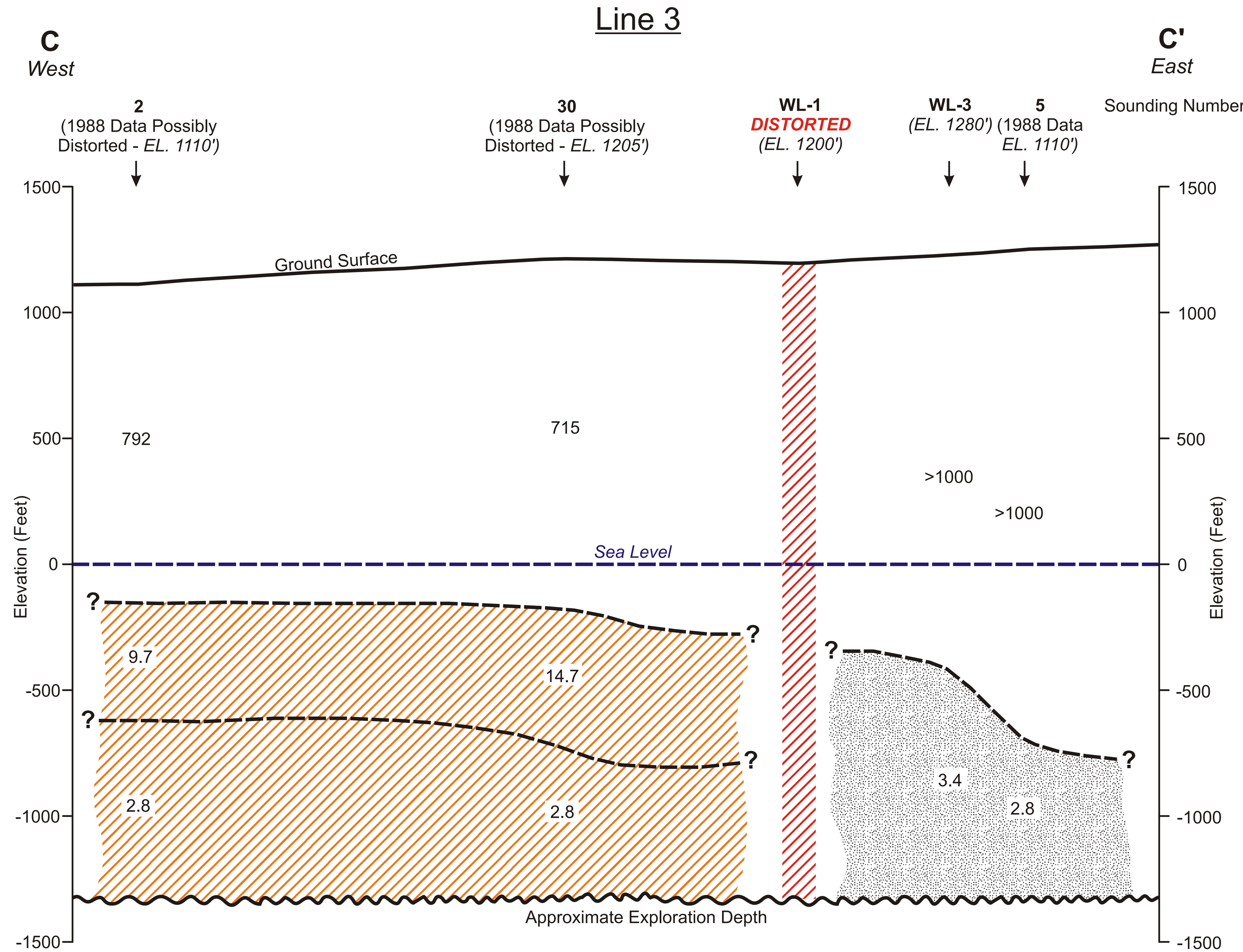
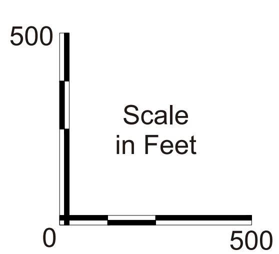
Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5068	February, 2007	HJV	RJB	1"=500"	5-2





Explanation

3.0 Resistivity (oHm-m)

Resistivity Boundary (Dashed Where Uncertain)

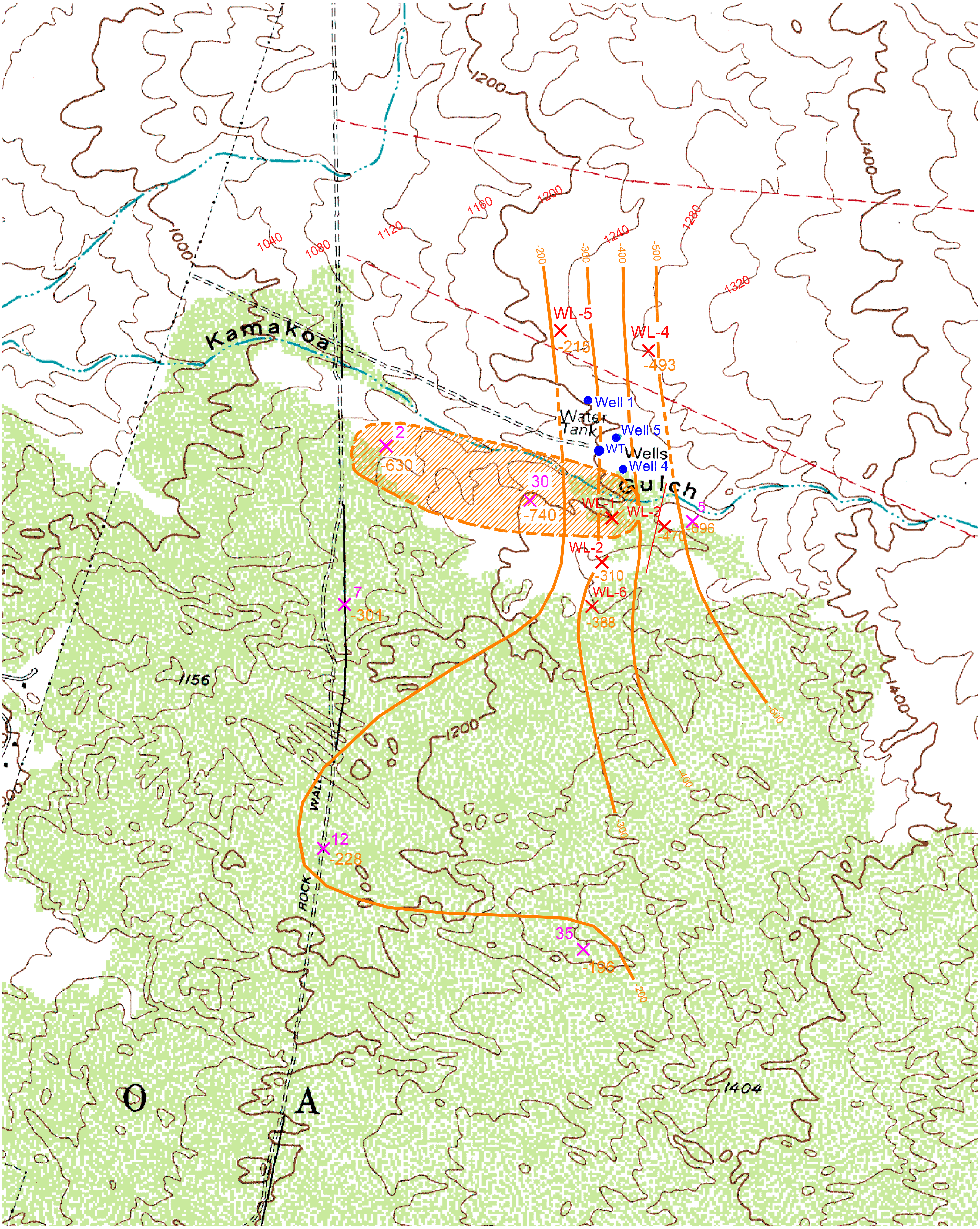
Possible Distortion

Dry Clay Poor or Fresh-Brackish Water Saturated Volcanics

Sea Water Saturated Volcanics

BLACKHAWK A DIVISION OF ZAPATAENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company	Geoelectric Cross-Section from 1-D TDEM Inversions Line 3 - Transect C-C' *North Well Field* *Waikoloa Village, Hawaii*

	Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
301 Commercial Road, Suite B Golden, Colorado 80401 Phone: (303) 278-8700 Fax: (303) 278-0789 Web: www.blackhawkgeo.com	5068	February, 2007	HJV	RJB	1"=500"	5-3



Explanation

WL-5 TDEM Sounding 2007

7 Previous TDEM Data

-215 Approximate Elevation of Top of Salt-Water Interface in Feet

WT Water Tank

Well 5 Water Well

-300 Contour of Sea-Water Interface, Elevation (Feet) (Dashed Where Uncertain)

Possible Distorted Sounding Area

N

0 1000 2000
Scale in Feet

BLACKHAWK A DIVISION OF ZAPATA ENGINEERING	Tom Nance Water Resource Engineering Waikoloa Land Company	Geophysical Survey Summary Interpretation Map *North Well Field* *Waikoloa Village, Hawaii*

301 Commercial Road, Suite B
Golden, Colorado 80401
Phone: (303) 278-8700
Fax: (303) 278-0789
Web: www.blackhawkgeo.com

Project No:	Date:	Drawn By:	Checked By:	Scale:	Figure:
5068	Feb., 2007	HJV	RJB	1"=1000'	5-4

6.0 CONCLUSIONS AND RECOMMENDATIONS

The main objective of the TDEM surveys in the North Well Field on the WLC Property on Hawaii was to explore for additional basal groundwater resources. The optimum locations for groundwater in the basal mode are expected to occur where the thickest lens of fresh-brackish water is detected floating on seawater.

The results from the TDEM surveys are shown on the summary map in Figure 5-4. The TDEM data indicate that beneath all soundings, a lens of basal mode fresh-brackish water occurs since seawater saturated volcanics are interpreted in all the soundings. It is likely, however, the freshwater lens situation is complicated by lateral obstructions to groundwater flow. The areas with the thickest lens of potential fresh-brackish water resource in the present survey are interpreted to occur beneath Soundings WL-3 (421 ft) and WL-4 (505 ft). These soundings are at the eastern (uphill) side of the property. Well 4 has a reported head of 15 ft which is significantly greater that the data from nearby Sounding WL-3 which shows a head of 10.3 ft. It is possible that steeply dipping structures are influencing groundwater flow and distorting the TDEM soundings located around the structures. This may account for differences between the existing wells, the 1988 TDEM and the present TDEM data. The general conclusion of the present survey combined with the previous survey and well data is that the area north of Kamakoa Gulch and to the east (uphill) from the present well field has the greatest potential for groundwater production.

Additional TDEM soundings located east of Soundings WL-3 and WL-4 will help define the extent of potential basal groundwater in this area of the property.

7.0 CERTIFICATION AND DISCLAIMER

All geophysical data analysis, interpretations, conclusions, and recommendations in this document have been prepared under the supervision of and reviewed by ZAPATA ENGINEERING P.A. Blackhawk Division, Senior Geophysicists and Engineers.

This geophysical investigation was conducted using sound scientific principles and state-of-the-art technology. A high degree of professionalism was maintained during all aspects of the project from the field investigation and data acquisition, through data processing, interpretation, and reporting. All original field data files, field notes and observations, and other pertinent information are maintained in the project files and are available for the client to review.

A geophysicist's certification of interpreted geophysical conditions comprises a declaration of his/her professional judgment. It does not constitute a warranty or guarantee, expressed or implied, nor does it relieve any other party of its responsibility to abide by contract documents, applicable codes, standards, regulations, or ordinances.

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